DETERIORATION IN SALTED BRIDGE DECKS

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Salting to prevent icing in the mountains or frost in the valleys is causing premature bridge deck deterioration in California. When de-icing salts reach the deck reinforcing steel, an electrolytic action begins that causes some of the steel to corrode. As the corrosive particles build up they expand against the concrete covering the steel. As the process continues the tensile strength of the concrete is exceeded, and intermittent horizontal cracks develop along the upper plane of the steel forming what is commonly referred to as an undersurface fracture. Traffic impact causes the concrete above the undersurface fracture to eventually ravel out leaving a pothole in the deck surface and exposed reinforcing steel (Fig. 1).

The only way that steel corrosion, and attendant potholing, can be prevented in decks subjected to salt is to prevent contact of salt and steel. Increasing cover and improving concrete quality appear to be means of protecting the steel from salt intrusion. But, because all concrete is porous to some degree and is usually cracked, especially bridge deck concrete, these means merely delay passage of salt. These improvements in concrete quality should not be de-emphasized because of their value in providing more durable decks in nonsalting or limited salting areas, but it must be realized that the only positive way to prevent salt intrusion on a concrete deck is to seal the deck with an impervious membrane.

There are several materials available that are practically impervious, such as rubber and plastic sheeting; but, unfortunately, either they cannot be bonded to the deck or the necessary protective overlay cannot be bonded to them. At present there are only 2 known materials available for use as an impervious deck membrane: a relatively thin layer of epoxy, usually coal tar extended epoxy, and a multilayer sandwich of coal tar and glass fabric. Most bridges now being built in California's mountain area are sealed with one or the other of these materials as are all bridges in both mountain and valley areas that have had decks restored.

The deck sealant material is the key to an effective preventive system on new bridges as well as to most systems for restored or rehabilitated decks. Hence, these 2 materials will be discussed in greater detail later. First, however, it might be best to discuss the complete deterioration picture with attention directed toward restoration because it is this subject that has the greatest immediate need.

The subject of restoration is much more interesting and complex than is the one of deterioration prevention. The only problem associated with prevention is in selecting an effective sealant membrane. On the other hand, problems associated with restoration are numerous. Some of the questions that need answering before restoration is done are as follows: Is the deck reparable or should it be replaced instead? Should there be total or partial restoration (the difference will be discussed later)? How long can traffic lanes be closed for repair? What type of patching materials should be used? What type of sealant should be used? Should the sealant be protected with an asphalt concrete (AC) overlay? In addition to these general questions there are numerous

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questions within each category concerning things such as application methods, AC thickness, weather condition restrictions during application, and method of measuring and paying.

This paper attempts to cover not all of the problems of deterioration restoration but only the more basic ones. It is more correctly a report on the current methods of bridge deck restoration in California. It discusses potholing deterioration only and makes no mention of scaling deterioration because it is the author's belief that a solution to deck potholing will also be a solution to deck scaling. The reverse is not true, however.

Figure 1. Beginning stage of deck surface potholes.

There are several vital facts to be remembered in assembling an effective restoration package. The restoration will not prevent continued deterioration if it does not include the removal of all concrete containing more than a certain value of chloride ions (at present this value is believed to be 500 ppm); the amount of corrosion necessary to spall concrete occurs with little loss of steel cross section; the sealant material should be flexible; and the sealant has to either be sufficiently tough to bear traffic, including chain abrasion in the mountains, or be protected by an overlay.

ELECTROLYSIS

Before accepting the premise that deterioration will continue after partial restoration, it is necessary to have knowledge of the electrolysis process. Even though the salt content in de-iced decks is usually fairly uniform at a given depth throughout the deck, the area affected by corrosion at the time of needed repairs usually represents only about 10 percent of the total deck surface area. The reason for this is that, in the electrolysis process, anode and cathode areas are established on a bar or on adjacent connected bars. With the damp, salt-impregnated concrete acting as an electrolyte, an electrical current flows from the anode to the cathode area. By the chemistry of the process, corrosion occurs at the anode but not at the cathode area. Most often the noncorrosive cathode area is considerably greater in size than is the corroded anode area.

If the salt-impregnated concrete is removed from the affected anode area, the current flow from that area is stopped. However, because the adjacent cathode areas usually contain sufficient salt to cause steel corrosion, there is no reason that some of these areas will not change polarity and become anodic. The degree to which anode areas develop and the intensity of their activity are dependent on the salt and moisture levels of the concrete.

TOTAL VERSUS PARTIAL RESTORATION

If continued deterioration in the deck is expected when only that portion of the concrete in the corroded area is removed (partial restoration, Fig. 2), why limit the removal? Why not remove all salt-laden concrete (total restoration, Fig. 3)? The primary answer is economy. On the average, total restoration costs from 3 to 5 times more than partial restoration (including a seal and overlay for each). This first cost difference is not, however, the only factor to be considered. Equally important is the life expectancy of the 2 systems. In addition, construction problems and allowable lane-closure time must be considered.

It is reasonable to assume that a total restoration, with a protective sealant, would have a normal expected life of 50 years because the finished product would closely approximate that of a new deck. The expected life of a partial repair, because of the continued corrosion potential, is much more difficult to predict. There have been

Figure 2. Partial restoration—concrete removed in anode areas only.

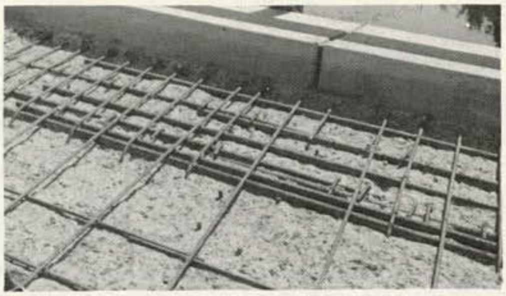

Figure 3. Total restoration—all salt-laden concrete removed.

similar partial repairs made to decks in California that were constructed with calcium chloride, and these decks are still performing with little or no maintenance after 11 to 20 years. Based on this performance history and the effectiveness of present sealants, it is reasonable to expect a minimum of 15 years additional life from a partially repaired salt-damaged deck. It is, therefore, estimated that a total restoration will have at least 3 times the life expectancy of a partial restoration. However, because the costs of total restoration are up to 5 times those of partial restoration, in the long run partial restoration would generally be more economical.

There are other factors that favor partial restoration over total restoration: (a) during total restoration of a continuous reinforced concrete structure, the concrete would normally be removed to the level of the longitudinal negative moment steel, and this would require supporting the structure, which under some conditions would not be practical; (b) partial repair work can normally be scheduled so that there will be no weekend lane closures, and this is practically impossible with total restoration work; (c) it is unrealistic to make a 50-year additional life comparison of structures that are already 10 years old or older because highway realignment, additional clearance or width requirements, or other actions result in a structure seldom remaining in the highway system for 50 years; and (d) before additional repairs are required to a partial restoration, improvements will have been made in restoration methods and materials that should further enhance partial restoration.

One question often asked when a minimum life expectancy of 15 years is designated for a partial repair job is, Why is it that an additional 15 years can be expected from the partial repair inasmuch as the deck being repaired is often only 10 years old? The answer lies in the reason that the repairs are being made. The primary purpose for making the repair is to fill potholes in the deck so that a safe, smooth riding surface is maintained. The actual loss of reinforcing steel due to the corrosion process up to that time in most cases has been small (Fig. 4). If the concrete over the steel could have taken the tensile stress exerted by the corrosive action, repairs would not have been required in 10 years. The equivalent tensile force on the concrete is expected because of continued corrosion after a partial repair, but the difference in performance is afforded by the AC overlay. As the concrete is pushed upward and undersurface fractures develop in it, the AC overlay will give with the pressure, remain intact, and prevent traffic from raveling

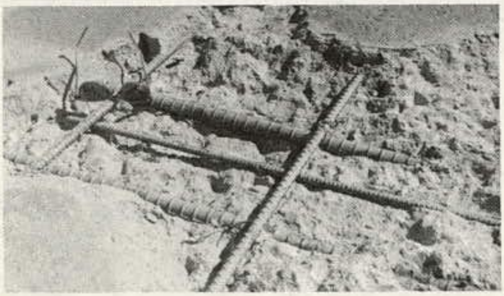

Figure 4. Corrosion sandblasted from steel (note minor pitting).

the concrete. This is not an assumption; there are several examples on California bridges. Therefore, by preventing potholing in the concrete, the life of the partial repair becomes dependent on the time required to reduce the total steel cross section in a given area to an unacceptable level. Again, from experience this time is estimated to be a minimum of 15 years.

CONTINUOUS PATCHING VERSUS RESTORATION

It has been advocated that, rather than patch, seal, and overlay by costly contracts when the decks start potholing, regular maintenance forces should patch potholes as they occur. Experience has shown that, without the protective overlay, a large number of patches made in a heavy freeze-thaw environment, no matter how well made, fail in less than a year. Furthermore, a large number of potholes form during the winter months, a time when patching is very difficult and potholes are hazardous to motorists. Maintenance patching, therefore, appears to be less expensive and more desirable at first glance, but, in the long run because of adverse factors mentioned, it would probably be more expensive, more hazardous, and definitely more unsightly.

PATCHING MATERIALS

After a decision is made on whether the type of restoration is to be partial or total, the type of patching material to be used must be decided. There is only 1 economical choice for total restoration: portland cement mortar. In partial restoration there are 2 choices: cement mortar or epoxy mortar. Epoxy mortar is more expensive than cement mortar, has a greater tendency to flow under a sustained load, is more sensitive to the weather during placing, but requires less lane-closing time. Because of the large difference in thermal coefficient of expansion of epoxy and portland cement concrete, a vital requirement of the epoxy in an epoxy mortar patch is that it be flexible enough to "give" during low temperature changes. Figure 5 shows an epoxy mortar patch being placed.

CONCRETE REMOVAL

Problems with removing concrete and cleaning reinforcing steel are the same regardless of the patching materials selected to fill the void. The main problem in concrete removal is to prevent fracture of the concrete under that which is to be removed. Limiting the weight of the chipping gun to about 30 lb appears to minimize this problem.

Not all damaged concrete areas are visible on the surface; frequently, incipient potholes exist in the form of undersurface fractures (Fig. 6). These areas should be located and treated the same way as the potholed areas. Sounding the concrete by striking it or by dragging an object over

Figure 5. Placing epoxy mortar patch.

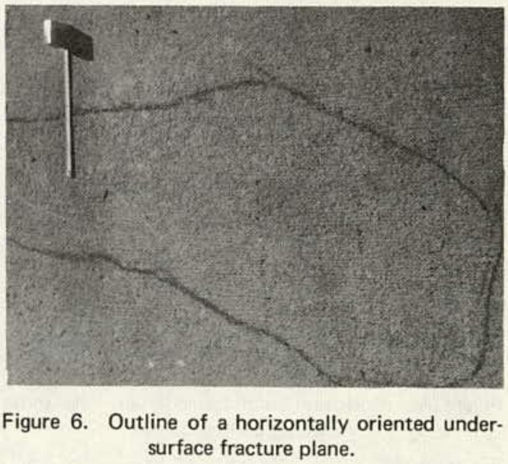

Figure 6. Outline of a horizontally oriented undersurface fracture plane.

it is the best way to locate undersurface fractures. A low-pitched "hollow" sound results when there is an undersurface fracture. The chain "broom" shown in Figure 7 has proved to be a very effective device for finding undersurface fractures in concrete bridge decks.

It would be advisable to locate all anodic areas, at least the ones in advanced stages, and remove the salt-laden concrete from the steel. It has not been fully explored, but the electrical potential method of measuring the voltage over a systematic grid of the deck and connecting points of equal potential to form contours shows promise of being effective in locating anodic areas.

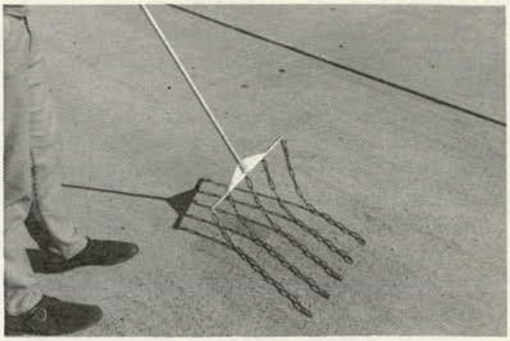

Figure 7. A chain broom for locating undersurface fracture planes.

DECK SEAL

When the patching is completed, the entire deck area is sealed. As previously stated, epoxy and coal tar-glass fabric are the 2 commonly used sealant systems.

The coal tar-glass fabric system (Fig. 8) has for several years proved its effectiveness in sealing industrial building roofs. Massachusetts highway engineers report that the coal tar system has also been an affective deck sealant in their state for several years. The ability of the material when properly formulated to reseal itself at temperatures normally found in bridge decks during the summer months probably is its greatest asset. This resealing property minimizes permanent damage (loss of integrity) to the system by reflection cracks over cracks caused by concrete shrinkage on new decks and by corrosion expansion on restored decks. The occurrence of reflection cracks can be reduced by increasing the flexibility of the coal tar at low temperatures by extending it with proper flexibilizers. Another point in favor of the coal tar system is that is requires much less surface preparation and is generally less expensive than the epoxy system. It does, however, normally require a longer lane-closure time than does an epoxy seal, and this fact alone could preclude its use under certain traffic conditions.

The coal tar, extended-epoxy system has some flexibility and, if properly compounded and placed, is not too severely damaged by minor cracking. However, its flexibility is much less than the coal tar-glass fabric system, and it would undoubtedly be permanently damaged by large or extensive cracking. This would severely reduce its sealing effectiveness as it has no resealing capability. The biggest problem with the epoxy sealant, though, occurs during placing as it is a very sophisticated material. It is very sensitive to low temperature, mixing practices, and moisture; it has a tendency to blister while still semifluid under certain deck and ambient temperature conditions; and it suffers from capillary action, manifested by pinhole voids in the hardened material, when aggregate of a certain size and shape is broadcast into it.

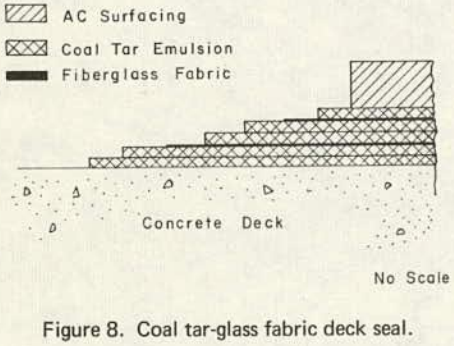

Figure 8. Coal tar-glass fabric deck seal.

The most economical and effective surface preparation for an epoxy sealant is sandblasting. The coal tar-glass fabric sealant requires little surface preparation. The epoxy membrane cannot endure more than about 3 years of tire-chain wear, so it must be protected where tire chains are used. (When placed on new decks in the valley, the epoxy membrane also becomes the decks' wearing surface and as such must bear tire traffic.) The coal tar-glass fabric system requires a protective overlay regardless of whether tire chains are used or not.

Aggregate is always broadcast into the epoxy membrane while it is still fluid. The sole purpose of the aggregate is to provide texturing when the epoxy membrane is also to be the wearing surface and to provide mechanical connectors when it is to be protected with an overlay. The coal tar-glass fabric system does not require mechanical connection as an emulsion tack coat bonds the asphalt concrete overlay to it.

ASPHALT CONCRETE OVERLAY

The best protective material found to date for either sealant is an asphalt concrete overlay. Thickness of the required overlay depends on the abuse it will be subjected to. Normally the thickness varies from 2 to 3 in. Asbestos has been added to some AC overlays to enable use of a higher percentage of asphalt for greater durability. The actual effectiveness of the asbestos has not been determined. If AC has not been down long enough to be kneaded by regular traffic during warm weather, it will normally ravel under traffic during cold or wet weather.

Most deck seals are not totally impermeable and could become ineffective if water were allowed to pond above them. AC surfacing is usually fairly permeable and water does pond in it. This ponding, however, can be markedly reduced, if not eliminated, by placing 2-in. diameter plastic "bleeder" pipes through the deck along the gutter line at about 20-ft spacing.

NONCORROSIVE DE-ICERS

The costly and complex problem of salt deterioration could be eliminated by the development and use of a noncorrosive de-icing material. Unfortunately, this panacea has not yet been found. Materials have been found that under certain conditions are effective de-icers and are noncorrosive to steel. But, they are either corrosive to the concrete, have too high a freezing point, or become corrosive to steel when concentrated (as could occur in deck cracks over the steel). Work is now under way to combine some of the more promising materials with an effective inhibitor.

CONCLUSION

There are still many unanswered questions on the subjects of deterioration prevention and restoration of salted bridge decks. This paper has attempted to open some areas of the subjects to stimulate thought and discussion in an attempt to hasten some of the answers. Several of the answers will be found only through research and experience. Both are time-consuming. In the meantime, immediate action is needed to reduce the deterioration problem; this action must be directed by engineering judgment, taking into account the vital factors of function, safety, economy, and effectiveness. Bare pavements through the use of salt, whether we like it or not, will probably continue for many years.